

This Page Is Inserted by IFW Operations  
and is not a part of the Official Record

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning documents *will not* correct images,  
please do not report the images to the  
Image Problem Mailbox.**

Express Mail No. EV 388910885 US

PATENT APPLICATION OF  
GARRIE DAVID HUISENGA,  
JAMES ALAN JOHNSON &  
JONATHON MICHAEL JONGSMA  
ENTITLED  
PROCESS DEVICE WITH SWITCHING POWER SUPPLY

Docket No. R11.12-0856

## PROCESS DEVICE WITH SWITCHING POWER SUPPLY

### BACKGROUND OF THE INVENTION

The present invention relates to process field devices of the type used to monitor or control operation of an industrial process. More specifically, the present invention relates to process field devices which communicate on a two wire process control loop and which are completely powered with power received from the two wire process control loop.

Process devices are used in industrial process control systems to monitor and/or control industrial processes. A control device is a process device which is used to control the process. Example control devices include pumps, valves, actuators, solenoids, motors, mixers, agitators, breakers, crushers, rollers, mills, ball millers, kneaders, filters, blenders, cyclones, centrifuges, towers, dryers, conveyors, separators, elevators, hoists, heaters, coolers, and other such equipment. A transmitter is a process device which is used to sense (or monitor) operation of the process, for example by monitoring a process variable such as temperature, pressure, flow, etc. The monitored process variable is transmitted so that it can be used by other equipment in the process, for example by a central control room. Another example process device is a process monitor or communicator which is used to monitor operation of the process, equipment used in the process such as process transmitters or process controllers, and control process devices, for

example by programming or sending instructions to the device.

Two wire process field devices are process devices which are located at a remote location or  
5 otherwise require electrical power which is received entirely through a connection to a two wire process control loop. A two wire process control loop refers to a wiring system utilizing two wires and which is used to carry information related to the process  
10 being monitored or controlled. For example, one standard type of two wire process control loop uses a 4-20mA current level to represent a process variable. In such a configuration, a transmitter can control the current level to a value, such as 10mA, which is  
15 representative of a sensed process variable such as pressure. Other process control loop configurations allow for the transmission of digital signals. The digital signals can be an alternative to transmission of an analog current level or can be in combination  
20 with transmission of the analog current level.

In order to reduce the amount of wiring required to couple to a process device, many process devices are entirely powered with power received from the two wire process control loop. Thus, the total  
25 amount of power available to the process device is limited. For example in a 4-20mA current loop, the total power available is limited by the lowest level at which the current level can be set (for example 3.6mA) and the maximum voltage drop available across

the device (for example something less than 24 volts) in an intrinsic safe location. This is less than 0.9 watts available to power the device.

In many cases, the functionality of a process device is limited by the amount of power which is available from the two wire process control loop. For example, additional functionality may require addition computational capabilities from a microprocessor. This increased computational power requires greater electrical power and may exceed the power budget available from the loop. In order to increase the amount of power available to circuitry in a process field device, field devices typically utilize highly efficient power supplies to convert power received from the two wire process control loop into a regulated voltage level for use by internal circuitry. One type of power supply, the switching regulator, has been used in process devices due to its efficiency in providing a regulated supply voltage to components in a field device. For example, the use of switching regulators is described in U.S. Patent No. 5,535,243, which issued July 9, 1996, entitled POWER SUPPLY FOR FIELD MOUNTED TRANSMITTER and U.S. Patent No. 5,973,942, which issued October 26, 1999, entitled START UP CIRCUIT FOR DC POWERED FIELD INSTRUMENT. However, a switching regulator may introduce noise into the process control loop which may alter or otherwise detrimentally affect transmission of information on the loop.

### SUMMARY

A process field device for coupling to a two wire process control loop includes a field device circuitry and a switching regulator configured to power the field device circuitry. A bulk capacitance is coupled to an input of the switching regulator and configured to provide power to the switching regulator. A series voltage regulator provides a regulated supply voltage to the bulk capacitance. A noise filter couples the series voltage regulator to the two wire process control loop and reduces noise due to the switching regulator in the two wire process control loop.

A method of providing power to a circuitry of a field device in a two wire process control loop including receiving power from the two wire process control loop and preregulating the received power to a regulated voltage level. Noise from the switching regulator is filtered from entering the two wire process control loop.

### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a simplified diagram showing a process control or monitoring system including a process device coupled to a two wire process control loop.

Figure 2 is a simplified block diagram of circuitry in a field device including a power supply for providing power to the device.

Figure 3 is a simplified block diagram of power supply circuitry in the field device.

Figure 4 is a schematic diagram showing one example embodiment of the power supply circuitry of  
5 the present invention.

Figure 5 is a schematic diagram showing another example embodiment of the power supply circuitry of the present invention.

Figure 6 is a graph illustrating signal  
10 noise versus time which shows the signal noise injected into a two wire process control loop.

Figure 7 is a graph of signal noise versus time similar to Figure 6 which illustrates the reduced signal noise due to the configuration of the  
15 present invention.

#### DETAILED DESCRIPTION

As discussed in the Background section, some types of process field devices are completely powered using power received from the same two wire  
20 process control loop which is used to transmit information related to the process. Figure 1 is a simplified diagram of an industrial process control or monitoring system 100 in which one type of two wire process field device, a process transmitter 102,  
25 couples to an industrial process, specifically process piping 104. Transmitter 102 also couples to a two wire process control loop 110 which connects to a control room 112. The process control loop 110 is illustrated as carrying a current  $I$  and may operate

in accordance with any technique including industrial standards such as the HART® communication standard, a Fieldbus or Profibus standard, etc. Although a process transmitter 102 is described, the present invention can be implemented in any type of process device in which efficient power conversion is desired. Control room 112 can comprise a remote location for use by operators or other service personnel, or can comprise any termination or location along the process control loop 110 or other location.

Figure 2 is a simplified block diagram of the transmitter 102 shown in Figure 1. Transmitter 102 includes a transducer 120 for coupling to a process. For example, the transducer 120 can be a sensor such as a pressure, temperature or other sensor for measuring a process variable. In a field device which is capable of controlling the process, the transducer can comprise, for example, a valve, heating element, etc. Field device circuitry 122 couples to the transducer 120 and is used, for example, to calibrate or compensate process variable measurements, calculate process variables, perform diagnostics, or any other function which may be performed in a field device. In general, additional functionality in the field device circuitry 122 will increase the power requirements of the circuitry 122. A power supply and I/O circuit 124 is shown coupling to field device circuitry 122 and to the two wire



process control loop 110. Circuitry 124 is used for communication over the two wire process control loop 110, for example to transmit a measured or calculated process variable over loop 110 to the control room  
5 112 shown in Figure 1. Circuitry 124 also provides a power output for providing all electrical power required by circuitry within the transmitter 102.

As discussed in the Background section, process field devices which are completely powered  
10 with power received from a process control loop may require a highly efficient voltage regulator in order to meet their power requirements. Typically, this means that a switching regulator is used to power the field device. One drawback of a switching regulator  
15 is that it requires a relatively large capacitors in order to operate without introducing noise into the system. This can be particularly problematic in environments in which large capacitance values cannot be used. For example, in order to meet intrinsic  
20 safety requirements, the amount of energy which a field device may store is limited. This makes it difficult to meet the requirements of having limited noise introduced into the two wire communication link, low power draw from the two wire communication  
25 loop along with maintaining the low capacitance necessary for intrinsic safety requirements.

Figure 3 is a simplified block diagram showing power supply circuitry 150 in greater detail. Power supply circuitry 150 couples to two wire

process control loop 110 and provides power to field device circuitry 122. The power supply circuitry 150 includes a switching regulator 152 which provides the power supply output to the field device 122. A bulk capacitor 154 provides an input to the switching regulator 152 and is powered by series voltage regulator 156. The series voltage regulator 156 is powered from the two wire process control loop 110 through filter circuitry 158. In accordance with the present invention, the configuration shown in Figure 3 substantially reduces the amount of noise generated by the switching regulator 152 which is injected back into two wire process control loop 110.

The configuration illustrated in Figure 3 provides a preregulator circuit 170 to the switching regulator 152 which generates a regulated input voltage on connection 164 for use by the switching regulator 152. For example, if the current drawn by the field device circuitry 122 suddenly increases, the switching regulator 152 draws power from bulk capacitor 154 and may not be able to respond fast enough to this current spike. If the switching regulator 158 is able to draw current directly from the process control loop 110, this current spike will introduce noise into loop 110. However, with the present invention, filter circuitry 158 reduces the response time of the regulator 156 such that the peak current draws from switching regulator 152 are forced to be fulfilled with energy from bulk capacitor 154

rather than from loop 110. The circuitry can be configured so that any noise which is introduced into the loop 110 is outside of the frequency range used for communication on loop 110. For example, higher  
5 frequency noise on loop 110 has a reduced effect on readings obtained in the control room 112. Therefore, if the preregulator circuitry 170 provides a low pass filter, the majority of the noise from the switching regulator 152 can be blocked from the two wire  
10 process control loop 110. However, the filter circuitry 158 should be implemented without the use of a large capacitance in order to meet intrinsic safety requirements. This means that traditional capacitive filtering techniques cannot be used in  
15 such an implementation.

With the present invention, the filter circuitry 158 of the series preregulator 170 is configured to utilize capacitors which are sufficiently small to meet intrinsic safety  
20 requirements while still providing sufficient filtering to prevent current variations from entering loop 110 due to the switching regulator 152. The filter circuitry 158 includes at least one active component to increase the filtering capabilities of  
25 the circuit. The active component can be, for example, a transistor such as a field effect transistor, a three terminal device, a non-linear device, or other component.

Figure 4 is a schematic diagram of one implementation of power supply circuitry 200 in accordance with the present invention. Power supply circuitry 200 is illustrated as being coupled through  
5 process control loop 110 to control room 112. The control room circuitry 112 is modeled as a 24 volt source in series with a 500 ohm resistance. The switching regulator is modeled as an A/C current source 202 which represents the noise introduced by  
10 the switching regulator into the circuitry. The bulk capacitor 154 is formed by capacitors C4, C5 and C6 along with intrinsic safety resistors R10 and R11. The voltage pre-regulator 156 includes an opamp configured to provide a regulated 10 volt output to  
15 the switching regulators. The opamp is configured with negative feedback with capacitor C3 and has its inverting input set to a voltage level by resistors R8 and R9. The non-inverting input is coupled to a voltage reference V2, such as a zener diode. In one  
20 embodiment, the operational amplifier comprises a TLC27L4 available from Texas Instruments. Resistor R4 is configured to provide a start up voltage to boot strap operation of regulator 156. Filter circuitry 158 includes an N-type depletion mode field effect  
25 transistor Q1 and provides an active element as discussed above. A small capacitor C2 is connected across the gate and drain of transistor Q1. During operation any noise present at the 10 volt power supply rail due to operation of the switching

regulator 152 will be filtered by capacitor C2 and resistor R3. Capacitor C2 and Resistor R3 enable increased filtering capabilities of Q1. This substantially decreases the amount of noise signal  
5 which enters the two wire process control loop.

Figure 5 is a circuit diagram of power supply circuitry 220 which represents another implementation in accordance with the present invention. However, in the configuration of Figure 5,  
10 filter circuitry 158 includes two active elements formed by transistors Q1 and Q2, an additional capacitor C1 of 47pF and additional resistor R2. This configuration provides two stages of filtering to further increase the filtering capabilities of the  
15 capacitors.

The particular switching regulator used with the circuitry can be selected as desired. In one configuration, two switching regulators are used to generate two voltages. For example, a LTC1771 from  
20 Linear Technology can be used to generate a 5.2 volt supply voltage and an LTC1474 can be used to generate a 3.0 volt supply voltage.

Figure 6 is a graph of signal amplitude versus time and illustrates the noise signal applied  
25 to a process control loop when no additional filtering is used. This loop noise is measured across a 500 Ohm resistive load. On the other hand, Figure 7 is the same graph showing the noise signal using the circuit configuration illustrated in Figure 5.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without  
5 departing from the spirit and scope of the invention. The present invention can be used with all types of field devices, although it is particularly applicable to those devices which are completely powered with power received from a two wire process control loop.  
10 However, the invention can be utilized with other process field devices in which there is a relatively tight power budget. Although particular circuitry and configurations are illustrated herein, the invention is not limited to these configurations.